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EVALUATION OF DIFFERENT WELL CONTROL METHODS CONCENTRATING ON THE APPLICATION OF CONVENTIONAL DRILLING TECHNIQUE

Saiful Syazni Bin Haji Saifulizan[1], Bashir Busahmin[1], Reddy Prasad D. M.[1] and Saber Elmabrouk[2]

[1]Petroleum and Chemical Engineering, Faculty of Engineering, Universiti Teknologi Brunei, Brunei Darussalam

[2]Department of Chemical and Petroleum Engineering, Libyan Academy for Postgraduate Studies, Janzur, Libya

E-Mail: bashir.abusahmin@utb.edu.bn

ABSTRACT

Over the past few decades, engineering failures have existed, and lack of knowledge, and safety practices have led to various catastrophic events of blowouts causing countless casualties and injuries to workers and individuals all around the world. Well control is a technique in oil and gas activities specifically when drilling oil and gas wells. Hydrostatic pressure and formation pressure should be a priority to prevent reservoir fluids from infiltrating the wellbore. The primary well control is commonly the primary barrier using the fluid column to prevent uncontrolled formation fluid flow into the wellbore by preserving pressure more substantial than formation pressure. The secondary well control provides the same purpose but involves using a piece of equipment known as a Blowout Preventer. The objective of this paper is to evaluate the effectiveness of different well control techniques of various well control methods, including the commonly used in petroleum engineering focusing on the application of conventional drilling. This study was conducted through a literature review. The analysis of the case studies synthesized to provide a comprehensive overview of the various well control methods. The findings suggested that conventional drilling techniques can be effective in controlling wellbore pressures, however, limitations existed in certain situations. Moreover, the parameters required controlling the well during a kick or a blowout is discussed to succeed in the application of well control methods in the oil and gas industry.

Keywords: gas kick, BOP, hydrostatic pressure, formation pressure, driller's method. LOT.

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1. INTRODUCTION

Well control is a system used in oil and gas operations for maintaining the fluid column of the hydrostatic pressure and formation pressure with the purpose to avoid an influx of reservoir fluids into the borehole, as the majority of well blowouts start from a kick in the well, well control is one of the systems that is applied in the upstream as a secondary barrier to kill the well, however proper installation of blowout preventer or BOP equipment is substantial, Well control is crucial in oil and gas exploration, particularly during drilling, workover, and completion operations [1] Well control has two types, primary well control, and secondary well control. The goal of primary well control is to maintain the hydrostatic pressure to be equivalent to or above the formation pressure about 200 psi (HP > FP) which is also known as overbalanced pressure to prevent the fluid influx into the well, in addition, subjective well-being depends on our perception of control (SWB). Individualists and collectivists, on the other hand, may prefer different kinds of perceptions of control, moreover [2] investigated the connections between affective cognitive and cultural variations in agency oriented primary control and adjustment oriented secondary control. Secondary well control is when the pressure of fluids within the wellbore is insufficient to stop formation fluids from entering the wellbore which is stopped by using the well control equipment, consequently, it is obligatory to further enhance the well control safety knowledge to gradually move drilling operations in the direction of scientific, secure, and refined technology development. Due to losses of well control during drilling operations, which resulted in a blowout, the upstream sector of the petroleum industry challenged substantial complications, which included: personnel working on the rig, devastation of oil-field equipment, significant financial loss for rig owners, and severe harm to the economy as well as the environment, in addition, formation kicks and reservoir pressure, among other well control issues, must be addressed in order to avoid the negative effects of offshore drilling's loss of well control, therefore, It is necessary to conduct a thorough inspection of various well control approaches to assess the efficiency related to conventional drilling techniques as well as to offer a recommendations on to which method to be used, because of hydrostatic pressure, as described in Figure 1, and is a non-moving fluid pressure that exists at any point in a usage hole because of the mud density and the amount of pressure is increased in proportion to depth [3,4]. Furthermore, HP is influenced by two parameters named fluid density and the fluid height of the hole, therefore, hydrostatic pressure is calculated by using Equation 1 or 2.

$$\text{Hydrostatic Pressure}\left(\frac{\text{Psi}}{\text{ft}}\right) = 0.052 \times \text{Mud Density (ppg)} \times \text{TVD (ft)} \tag{1}$$

$$\text{HP (Kpa/m)} = 0.00981 \times \text{Mud Density (kg/m}^3) \times \text{TVD(m)} \tag{2}$$

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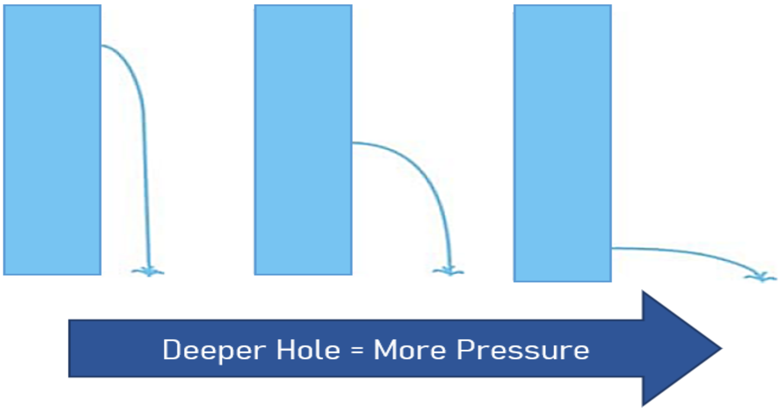

Figure-1. An image visualizing how different depth affects the hydrostatic pressure.

In addition, the pressure generated by the fluids in the formation is known as the reservoir pressure, based on the subsurface condition, reservoir pressure was classified to be normal, subnormal, and abnormal Table-1 depending on the pressure gradient value Figure-2.

Table-1. Description of different types of reservoirs pressure. [5,6]

Types of Reservoir Pressure	Descriptions
Normal	The pressure that is generated by a fluid column inside the reservoir at a particular depth is referred to as normal reservoir pressure, and additionally identified as hydrostatic pressure. With increasing depth, the pressure increases, and the increasing rate is directly correlated with water gradient. The pressure gradient in the reservoir under normal pressure is 0.433 psi/ft. to 0.5 psi/ft.
Subnormal	Subnormal pressured reservoir has a lower pressure gradient than usual which is less than 0.433 psi/ft. This is caused by several things, such as the existence of rocks that have low permeability, a high degree of porosity, or an absence of fluid connectivity between distinct reservoir zones.
Abnormal	A reservoir with an unusually high-pressure gradient usually greater than 0.5 psi/ft. is under abnormal pressure. It might be the result of tectonic plate movement, compaction, or the existence of underlying overpressure zones. Because there is a higher chance of a wellbore stability issues and influx of hydrocarbon, drilling and completing a well with an abnormal pressured reservoir might be difficult.

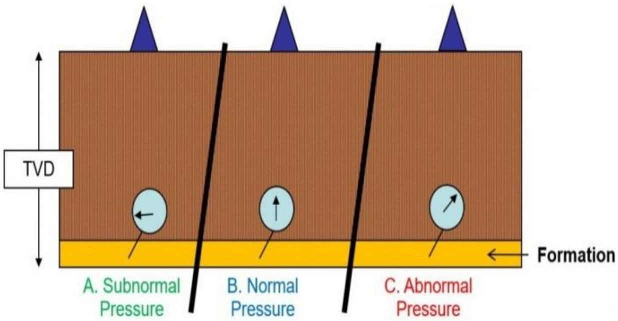

Figure-2. The comparison of normal, subnormal, and abnormal reservoir pressure [5].

However, well control always has the same goal, the design for well control changes based on different drilling techniques [6]. Therefore, the main purpose of this paper is to evaluate different well control methods in terms of the effectiveness and efficiency of the conventional drilling techniques. In addition, this paper provides an improved knowledge on well control and further understanding on how to address the issues of well control and steps taken towards experiencing a kick or blowouts.

2. WELL CONTROL PERCEPTIONS

2.1 Formation Integrity Test and Leak off Test Behaviors

Formation Integrity Test (FIT), used to test the formation strength, where the pressure is set to a limit to check if the formation does not leak to a certain pressure, while drilling into the casing shoe and that is the initial step [7,8], Figure-3 presents both FIT and Leak off test (LOT)

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behavior, where LOT is typically carried out right away after the cement job has been conducted, drilling is resumed i.e. drilling into a new casing shoe to evaluate the strength of the formation in a virgin hole and the well is sealed off throughout the test, in addition, drilling mud is injected down the well to progressively increase the pressure on the formation, therefore, the results of the test determines the weight of the drilling mud that can be injected into the well [9].

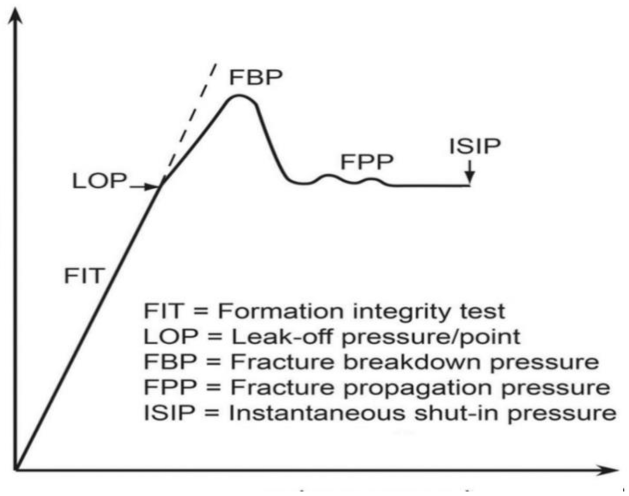

Figure-3. Formation Integrity Test and Leak-Off Test, [7].

2.2 Well Kick

Well Kick is an early indication before a blowout during oil and gas drilling operations. It occurs when the hydrostatic pressure inside the well is much lower compared to the reservoir pore pressure, or it can be said as loss of primary control which leads to reservoir fluids to begin flowing back up the well to the surface, where there are several reasons that caused a kick, some of them include insufficient mud in the hole and this leads to a loss of hydrostatic pressure, failure to fill in the hole properly during tripping, swabbing, and surging effect as shown in Figure-4 [10].

Table-2. A comparison between the effect of Swab and Surge Pressures. [11].

Swab	Surge
Bottom Hole Pressure (BHP) is decreased which is caused by pulling the drill string in a way that lessens the effective BHP because BHP is lower than reservoir pressure resulting in a flow coming in from the reservoir.	Bottom Hole Pressure (BHP) is increased which is caused by RIH piston effect pressurizing the wellbore below the bit. By pressurizing the wellbore, this may cause losses by injecting mud into wellbore by squeezing or worst breakdown the formation, failure to fill hole properly during tripping, and loss of hydrostatic pressure.

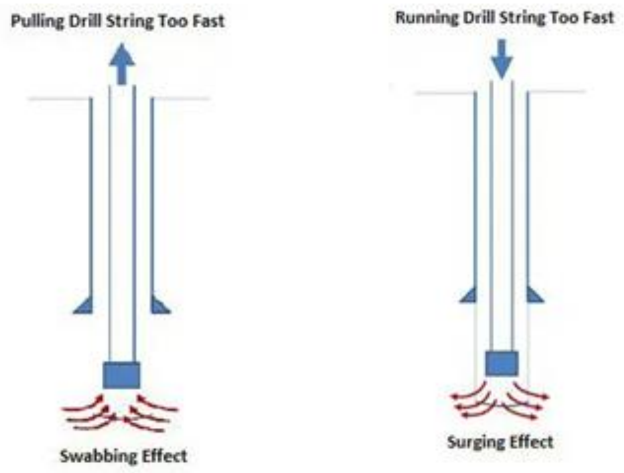

Figure-4. Swab and Surge Profile, [12].

2.3 Types for Well Control

Primary and secondary well control are the two distinct kinds of well control. Primary well control involves keeping the wellbore's hydrostatic pressure at or above the formation pressure, about 200 psi, a synonym known as an overbalanced pressure, where the purpose is to prevent the influx of fluid. Secondary well control involves the installation of proper equipment before drilling the surface hole to prevent the entry of formation fluids into the wellbore when pressure is applied from the drilling mud Because of the complicated geological conditions and operational environments, well control is complicated, dynamic, and prone to high levels of uncertainty. As of recently, quantitative hazard evaluation in well control isn't incorporating human mistakes, tools malfunction, that includes mechanical and electrical parts. [13], A shut-in in well control is a method of preventing fluid flow through the borehole from the reservoir. Both hard and soft shut-in are crucial techniques to control the well and was applied in various situations based on the severity of the well condition, however, careful consideration should be given to the conditions of the wellbore, reservoir characteristics, and the personnel when choosing the best shut-in technique. A hard shut-in happens when the blowout preventer (BOP) suddenly seals-off and ceases the circulation of fluids. On an occasion when there is an urgent threat of an uncontrolled flow or a blowout, a hard shut-in, a quick and forceful approach of well control is employed, alternatively, a soft shut-in is a slow decrease in pressure and flow rate that is achieved by regulating the choke manifold. Furthermore, using this technique, the operator steadily lowers the pressure inside the wellbore and gets the well under control prior to starting a hard shut in. Moreover, when there is a less imminent risk of a blowout, a soft shut-in, a more regulated type of well control, is employed and the wellbore pressure must be carefully monitored to prevent any further issues and the overarching research examining the transient pressure in The BOP shut-off process utilizing water hammer hypothesis isn't as per this present reality circumstance because of the long BOP preventer shut-off periods [14].

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2.4 Methods for Well Control

There are nine types of well control methods and are broken down into two sections, circulating and non-circulating well control techniques. Under the circulating method, there are Wait and Weight method, Driller's method, circulate and weight, concurrent and reverse circulation method. While bull-heading, volumetric method, dynamic kill technique, lubricate and bleed off methods are classified under a non-circulating well control techniques [17, 18].

3. RESULTS AND DISCUSSIONS

3.1 Fracture Pressure

Fracture pressure refers to the pressure where the formation withstands a certain amount of pressure before the formation breaks down, as shown in Figure-5 and when this happens, the rock forms fractures and reservoir fluids in the well escape and get lost inside the reservoir, as a result, the maximum pressure at which this occurs is called fracture point [6].

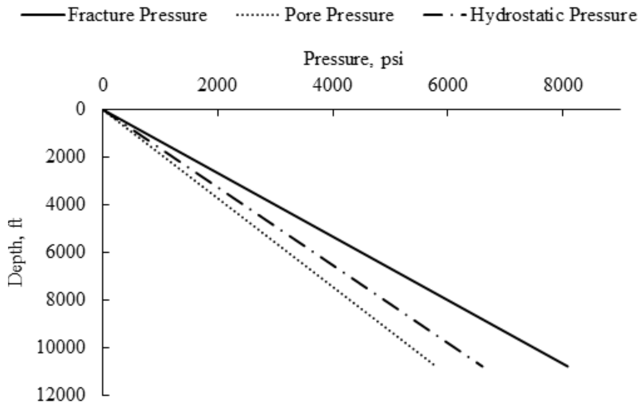

Figure-5. Various pressure behavior against depth.

Figure-6 Because of there are two methods namely Driller's and Wait and Weight method applied in oil and gas industry due to their popularity, in addition, international well control form, IWCF is the body to evaluate the method for killing the well, however each drilling company has a policy to adhere to and follow. IWCF kill sheet calculations is available and the data required were obtained from [15, 16] and is shown in Table-3.

Table-3. Well Data.

Hole ID	12.25 inch
Measured depth	10,990 feet
True vertical depth	10,770 feet
Casing	Set @7280 feet, 13,375 ID
Drill pipe	0.01776 feet
Heavy-weight drill pipe	0.0088 bbl./ft.
Drill collar	0.0077 bbl./ft.
Volume from mud pumps to rig floor	10 bbl.
Annular volume between drill collar and an open hole	0.0837 bbl./ft.
Annular volume between drill pipe, heavy weight drill pipe & open hole	0.1204 bbl./ft.
Annular volume between drill pipe, heavy weight drill pipe & cased hole	0.1292 bbl./ft.
Mud pumps output	0.12 bbl./stk.
Pump #1	34 SPM @500 psi, 40 SPM @ 1100 psi
Pump #2	30 SPM @600 psi, 40 SPM @ 1080 psi
Actual surface volume	440 bbl.
Surface leak-off pressure	1970 psi
SIDPP	450 psi
SICP	500 psi
PG	14 bbl.
Mud weight at the time of the kick	11.4 ppg.

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The initial task is to determine the maximum allowable drilling fluid density, equation 3 which is used to calculate the maximum allowable annular surface pressure. Therefore, the maximum allowable drilling fluid density or maximum allowable mud weight (MAMW), equation 4 represents the limit weight of the drilling mud that can be pumped into the well and exceeding the value will break the formation and creates an excessive fluid loss in the formation, as well as causing the loss of the well.

$$MAMW\ (ppg) = \frac{Leak\ off\ pressure\ from\ test(psi)}{0.052 \times Shoe\ TVD(ft)} + Drilling\ fluid\ density\ at\ test(PPG) \qquad (3)$$

$$MAASP\ (psi) = (MAMW(ppg) - Current\ density(ppg)) \times 0.052 \times TVD(ft) \qquad (4)$$

Figure-6 presents the effect of different mud densities against the hydrostatic pressure. It gives an indication where the initial barrier for well control is the mud weight where it must be higher than the formation pore pressure (PP) and to avoid a kick or breaking the formation, the fracture pressure (FP) must be less. Using the current drilling pressure gradient of 0.59 psi/ft, the hydrostatic pressure is within the envelope of the pore pressure and the fracture gradient. Using the pressure gradient of 0.5 psi/ft causes a kick as it must be less than the pore pressure. While operating within an extremely heavy drilling mud in this case with a pressure gradient of 0.8 psi/ft will create the formation to breakdown and this leads to the loss of the well. Moreover, the mud selection for each section of casing can be determined based on the same concept where the mud weight should be greater than that of the ore pressure and less than fracture pressure.

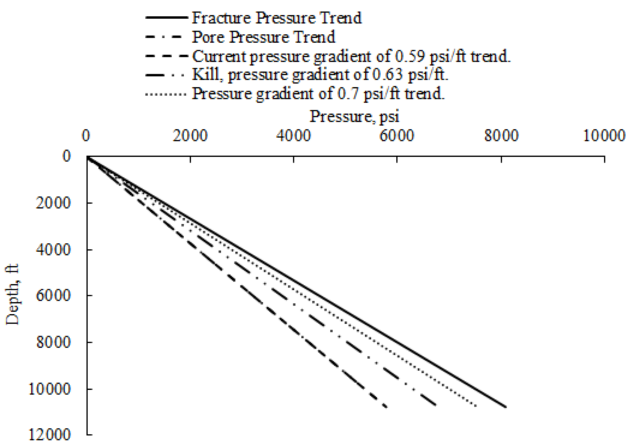

Figure-6. Pressure Gradient Curves.

Figure-6 shows the comparison of the current mud weight and the kill mud designed for the well. The current pressure gradient used is 0.59 psi/ft while for the kill pressure gradient is 0.63 psi/ft. Based on the trends presented, both the current and the kill pressure gradients are within the parameters on not exceeding the fracture gradient while being above pore pressure gradient, in addition, the kill mud could be added more weight up to 0.7 psi/ft.

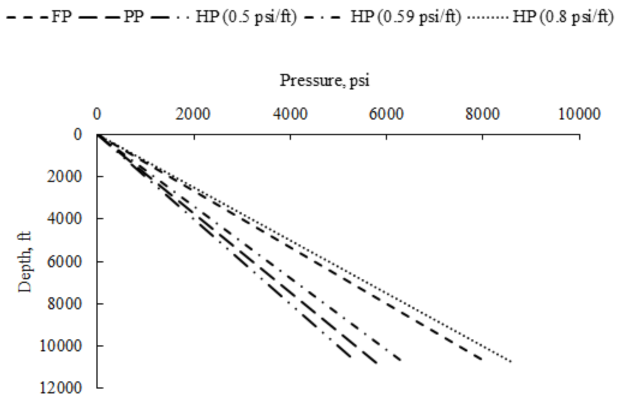

Figure-7. Different pressure values versus the depth.

ICP is the amount of pressure measured when drilling mud was pumped through the wellbore at the surface. It refers to the initial pressure needed to begin circulating the drilling fluid and to eliminate the borehole losses due friction, where FCP, on the contrary, is a pressure value measured at the surface when the drilling mud was flowing continuously after the killing of the well and assessed using equations 5,6 and 7.

$$\text{ICP} = \text{Dynamic Pressure loss (psi)} + \text{SIDPP(psi)} \qquad (5)$$

$$\text{FCP} = \frac{\text{Kill mud Density}}{\text{Current mud density}} \times \text{Dynamic Pressure loss (psi)} \quad \text{(Using mud density)} \qquad (6)$$

$$\text{FCP} = \frac{\text{Kill mud gradient}}{\text{Current mud gradient}} \times \text{Dynamic Pressure loss (psi)} \quad \text{(Using mud gradient)} \qquad (7)$$

The difference between ICP and FCP gives the amount of pressure loss during the whole circulation process. For this case study, the ICP is 950 psi and the FCP is 535 psi. Therefore, the difference is 415 psi, and this value can be divided by the pump stroke to give the pressure loss per stroke as seen in equations 8 and 9.

$$ICP - FCP = 950 - 535 \ = 415\, psi \qquad (8)$$

$$\frac{415 \text{ psi}}{1495 \text{ stroke}} = 0.27759 \frac{\text{psi}}{\text{stks}} \times 100 \quad \approx 27.75 \frac{\text{psi}}{100 \text{ stks}} \qquad (9)$$

This means that for every hundred strokes, it is expected to lose 27.75 psi. Figure-8 presents an example of different case scenarios when the displacement capability of the pump is different, producing different values of strokes. Additionally, Figure-9 shows the comparison of the scenarios using different pump strokes capability. Moreover, the current pump strokes is 1495 strokes to circulate the kill mud in the hole when the shut in drill pipe pressure is 950 psi, therefore, it takes 44 minutes to complete the cycle and the pressure loss per stroke is 0.2776, as a result it takes 1000 strokes to circulate the mud, however the pressure loss becomes higher. In this case, the

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loss experienced 0.415 psi per strokes. When the pump rate is slow with two thousand strokes to circulate the kill mud, then the time is longer but the pressure loss per stroke is lower because the movement of the fluid inside the well is slow. From the comparison, where higher capability of pumps that are capable to produce faster strokes per minutes are favorable to kill the well, however, that depends on several factors such as SPM value, the condition of the wellbore, reservoir characteristics, type of the drilling fluid utilized, and the equipment used.

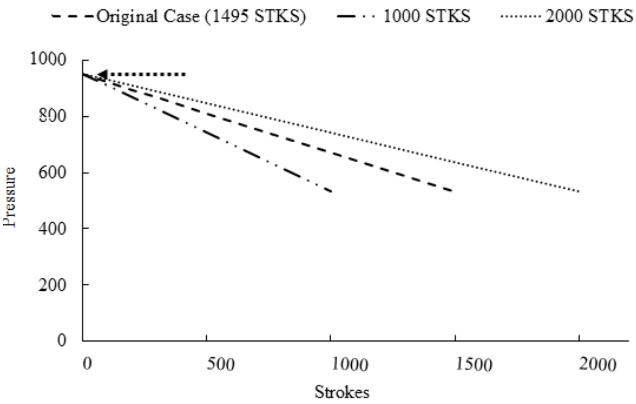

Figure-8. Pressure vs Number of Strokes.

4. CONCLUSIONS

The necessity for well control in becoming certain about the safety and the effectiveness of drilling operations. According to this study paper, using traditional drilling methods such as wellbore monitoring and drilling fluid circulation is essential to prevent and manage well control issues. In addition, automated drilling and real-time monitoring systems improve the efficiency of conventional drilling operations. While are more useful in certain cases depending on the well. One such case is when there is a high gas flow rate, lubricate and bleed off methods are the most efficient however, two types on how to control the well in terms of the procedures discussed hard shut-in and soft shut-in. The annular preventers are promptly sealed-off following the shutdown of the pumps via the hard shut-in operation. In soft shut-in methods, the choke opens prior to shutting the preventers, and it is subsequently sealed-off after the preventers have been shut. In well control activities within the oil and gas sector, the IWCF kill sheet is a crucial, because it gives a structured and a uniform strategy for managing the well operations, assuring the security of workers and tools throughout drilling operations.

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Conflicts of Interest

The authors declare no conflict of interest.

Nomenclature

TVD = True Vertical Depth
BHP = Bottom Hole Pressure
BOP = Blowout Preventer
Psi = Pounds per square inch
Psi/ft. = Pounds per square inch per foot
LOT = Leak-off Test
FIT = Formation Integrity Test
RIH = Run in hole
m = meter
m^3 = Cubic meter
ft. = feet
bbl. = barrel
HP = Hydrostatic Pressure
FP = Fracture Pressure or Formation Pressure
W&W = Wait & Weigh
IWCF = International Well Control Forum
MAMW = Maximum Allowable Mud Weight
MAASP = Maximum Allowable Annular Surface Pressure
SPM = Strokes per Minute
SIDPP = Shut in Drill Pipe Pressure
SICP = Shut in Casing Pressure
STKS = Strokes
DP = Drill Pipe
DC = Drill Collar
MD = Measured Depth
ICP = Initial Casing Pressure
FCP = Final casing Pressure
ρ = Density or Mud Weight
h = Thickness or Height
Do = Outer Diameter
Di = Inner Diameter
0.052 = Constant Factor in SI units
0.00981 = Constant Factor in metric units
PG = Pit gain

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